

What is Claimed:

- 1 1. A method for desalinating a solution containing sparingly soluble
2 solute comprising the steps of:
3 (a) introducing a solution having sparingly soluble solutes and
4 nucleation crystals to the high pressure side of a first semi-permeable
5 membrane barrier to produce a retentate stream on the high pressure side of
6 the first semi-permeable membrane barrier, and a permeate stream on the low
7 pressure side of the first semi-permeable membrane barrier having reduced
8 concentrations of the sparingly soluble solutes;
9 (b) introducing the permeate stream produced in step (a) to the high
10 pressure side of a second semi-permeable membrane barrier to produce a
11 second retentate stream on the high pressure side of the second semi-
12 permeable membrane barrier, and a product stream on the low pressure side of
13 the second semi-permeable membrane barrier with substantially lower
14 concentrations of sparingly soluble and soluble solutes compared to the solution
15 initially introduced in step (a); and
16 (c) returning a majority fraction of the retentate stream rejected by
17 the first semi-permeable membrane barrier containing a majority of the
18 nucleation crystals to the solution that is introduced to the high pressure side of
19 the first semi-permeable membrane barrier.
- 1 2. The method of claim 1 further comprising the step:
2 (d) returning a majority fraction of the second retentate stream
3 rejected by the second semi-permeable membrane barrier to the solution that
4 is introduced into the high pressure side of the first semi-permeable
5 membrane barrier.
- 1 3. The method of claim 1 wherein the initial solution is a heated
2 saline solution.
- 1 4. The method of claim 1 wherein a portion of the solution
2 introduced to the high pressure side of the first semi-permeable membrane
3 barrier in step (a) is bypassed around the first semi-permeable membrane

4 barrier and is introduced to the high pressure side of the second semi-
5 permeable membrane barrier.

1 5. The method of claim 1 wherein a majority fraction of the
2 retentate stream rejected by the first semi-permeable membrane barrier
3 containing a majority of the nucleation crystals is desupersaturated before said
4 stream is returned to the solution introduced to the high pressure side of the
5 first semi-permeable membrane barrier.

1 6. The method of claim 1 wherein the first semi-permeable
2 membrane barrier is a nanofiltration membrane.

1 7. The method of claim 1 wherein the second semi-permeable
2 membrane barrier is a reverse osmosis membrane.

1 8. The method of claim 1 wherein the first semi-permeable
2 membrane barrier is contained in tubular membrane modules.

1 9. The method of claim 1 wherein the second semi-permeable
2 membrane barrier is contained in spiral-wound membrane elements.

1 10. The method of claim 1 wherein the sparingly soluble solutes in
2 the initial solution include calcium, sulfate and silica.

1 11. The method of claim 1 wherein the nucleation crystals in the
2 solution of step (a) which is added to the high pressure side of the first semi-
3 permeable membrane barrier are added to the solution upon startup, and are
4 selected from the group consisting of calcium sulfate, calcium carbonate,
5 calcium phosphate, and silica.

1 12. The method of claim 1 wherein the initial solution is a saline
2 solution comprised of water containing between 3,000 and 20,000 mg/L of total
3 dissolved solids.

1 13. The method of claim 1 wherein the solution produced on the low
2 pressure side of the second semi-permeable membrane barrier is water
3 containing less than 500 mg/L of total dissolved solids.

1 14. The method of claim 1 wherein the water content of the product
2 stream produced on the low pressure side of the second semi-permeable
3 membrane barrier is greater than or equal to 80% of the water content of the

4 solution introduced to the high pressure side of the first semi-permeable
5 membrane barrier.

1 15. The method of claim 1 wherein the solution introduced to the
2 high pressure side of the first semi-permeable membrane barrier is agricultural
3 drainage water.

1 16. The method of claim 1 wherein the solution introduced to the
2 high pressure side of the first semi-permeable membrane barrier is
3 groundwater.

1 17. The method of claim 1 wherein the solution introduced to the
2 high pressure side of the first semi-permeable membrane barrier is a brine
3 stream produced in a separate water treatment process.

1 18. A method of desalinating a saline solution containing sparingly
2 soluble solutes comprising the steps of:

3 (a) introducing a saline solution containing sparingly soluble solutes
4 and nucleation crystals to the high pressure side of a first semi-permeable
5 membrane barrier to produce a retentate stream on the high pressure side of
6 the first semi-permeable membrane barrier, and a permeate solution on the low
7 pressure side of the first semi-permeable membrane barrier containing reduced
8 concentrations of the sparingly soluble solutes;

9 (b) introducing the permeate solution produced on the low pressure
10 side of the first semi-permeable membrane barrier to the high pressure side of
11 a second semi-permeable membrane barrier to produce a second retentate
12 stream on the high-pressure side of the second semi-permeable membrane
13 barrier, and a product solution on the low pressure side of the second semi-
14 permeable membrane barrier with substantially lower concentrations of
15 sparingly soluble and soluble solutes compared to the saline solution initially
16 introduced in step (a);

17 (c) separating the retentate stream rejected by the first semi-
18 permeable membrane barrier into a majority fraction solution containing a
19 majority of the nucleation crystals and a minority fraction solution containing a
20 minority of the nucleation crystals;

21 (d) returning the majority fraction solution directly to the saline
22 solution that is introduced to the high pressure side of the first semi-permeable
23 membrane barrier;

24 (e) separating the minority fraction solution into: (i) a first-fraction
25 solution with a higher level of suspended solids, and (ii) a second-fraction
26 solution with a lower level of suspended solids;

27 (f) returning a portion of the first-fraction solution with a higher
28 level of suspended solids to the saline solution that is introduced to the high
29 pressure side of the first semi-permeable membrane barrier; and

30 (g) returning the second retentate stream to the saline solution that
31 is introduced to the high pressure side of the first semi-permeable membrane
32 barrier.

1 19. The method of claim 18 wherein the separation of the minority
2 fraction solution in step (e) is accomplished using a gravity settling tank,
3 centrifuge, hydrocyclone or filter.

1 20. The method of claim 18 wherein the first-fraction solution with a
2 higher level of suspended solids is further split into (i) a discharge fraction and
3 (ii) a recovery fraction with the recovery fraction being returned and introduced
4 into the saline solution that is introduced into the high pressure side of the first
5 semi-permeable membrane barrier.

1 21. The method of claim 18 wherein the second-fraction solution with
2 a lower level of suspended solids is further split into (i) a discharge fraction and
3 (ii) recovery fraction with said recovery fraction being returned and introduced
4 into the saline solution that is introduced into the high pressure side of the first
5 semi-permeable membrane barrier.

1 22. The method of claim 18 wherein a fraction of the discharge
2 fraction is combined with the product stream produced on the low pressure side
3 of the second semi-permeable membrane barrier to effect a reduction in the
4 agronomic sodium adsorption ratio of said solution.

1 23. The method of claim 18 wherein the initial saline solution is
2 heated.

1 24. The method of claim 18 wherein saline solution is introduced into
2 the high pressure side of the second semi-permeable membrane barrier which
3 does not pass through the first semi-permeable membrane barrier.

1 25. The method of claim 18 wherein the retentate stream rejected by
2 the first semi-permeable membrane barrier containing a majority of the
3 nucleation crystals is desupersaturated before the solution is returned to the
4 high pressure side of the first semi-permeable membrane barrier.

1 26. The method of claim 18 wherein the first semi-permeable
2 membrane barrier is selected from the class of nanofiltration membranes.

1 27. The method of claim 18 wherein the second semi-permeable
2 membrane barrier is selected from the class of reverse osmosis membranes.

1 28. The method of claim 18 wherein the first semi-permeable
2 membrane barrier is contained in tubular membrane modules.

1 29. The method of claim 18 wherein the second semi-permeable
2 membrane barrier is contained in spiral-wound membrane elements.

1 30. The method of claim 18 wherein the sparingly soluble solutes in
2 the initial saline solution are calcium sulfate and silica.

1 31. The method of claim 18 wherein the seed nucleation crystals
2 added upon startup are selected from the group of calcium sulfate, calcium
3 carbonate, calcium phosphate, and silica.

1 32. The method of claim 18 wherein the initial saline solution is
2 water containing between 3,000 and 20,000 mg/L of total dissolved solids.

1 33. The method of claim 18 wherein the solution produced on the low
2 pressure side of the second semi-permeable membrane barrier is water
3 containing less than 500 mg/L of total dissolved solids.

1 34. The method of claim 18 wherein the water content of the
2 solution produced on the low pressure side of the second semi-permeable
3 membrane barrier is greater than or equal to 80% of the water content of the
4 initial saline solution.

1 35. The method of claim 18 wherein the initial saline solution is
2 agricultural drainage water.

1 36. The method of claim 18 wherein the initial saline solution is
2 groundwater.

1 37. The method of claim 18 wherein the initial saline solution is the
2 brine stream produced in a separate water treatment process.

1 38. A system for desalinating a solution containing soluble and
2 sparingly soluble solutes comprising:

3 (a) a first semi-permeable membrane barrier having a high-
4 pressure side and a low-pressure side for receiving a feed stream on the
5 high-pressure side and producing:

6 a permeate stream on the low-pressure side having reduced
7 concentrations of sparingly soluble solutes as compared to the
8 feed stream, and

9 a first retentate stream on the high-pressure side;

10 (b) a second semi-permeable membrane barrier having a low
11 pressure side and a high-pressure side in fluid communication with, and
12 downstream of, the first semi-permeable membrane for receiving the
13 permeate stream on the high-pressure side and producing:

14 a second retentate stream on the high-pressure side, and

15 a product water stream on the low-pressure side having
16 substantially lower concentrations of sparingly soluble and
17 soluble solutes compared to the feed stream; and

18 (c) means for separating solids from the first retentate
19 stream into a first fraction solution having a higher level of suspended
20 solids and a second fraction solution with a lower level of suspended
21 solids, said solid separating means in fluid communication with the high-
22 pressure side of the first semi-permeable membrane.

1 39. The system of claim 38 wherein said separating means is
2 selected from the group consisting of: a gravity settling tank, a centrifuge, a
3 hydrocyclone and a filter.

1 40. The system of claim 38 further comprising means for joining a
2 stream from the solid separating means and a stream from the high-pressure
3 side of the second semi-permeable membrane with the feed stream.

1 41. The system of claim 38 further comprising:

2 (d) means for separating the first retentate stream into a
3 majority fraction solution and a minority fraction solution upstream of said
4 solid-separating means, wherein said minority fraction solution is in fluid
5 communication with said solid separating means and said majority fraction
6 solution is in fluid communication with said high-pressure side of said first semi-
7 permeable membrane barrier.

1 42. The system of claim 38 further comprising:

2 (d) means for passing a portion of the feed stream directly to
3 the high-pressure side of the second semi-permeable membrane.

1 43. The system of claim 38 further comprising:

2 (d) means for heating the feed stream.

1 44. The system of claim 38 further comprising means for splitting
2 said first fraction solution into a high-solid recycle stream and a high-solid
3 discharge stream.

1 45. The system of claim 38 including means for splitting said second
2 fraction solution into a low-solid recycle stream and a low-solid discharge
3 stream.

1 46. The system of claim 41 further including desupersaturating
2 means to receive said majority fraction solution and said second fraction
3 solution.

1 47. The system of claim 46 wherein said desupersaturating means is
2 a stirred vessel.

1 48. The system of claim 44 further including adjustment means for
2 controlling the agronomic sodium absorption ratio of said product water stream,
3 said adjustment means allowing a controlled amount of said high-solid
4 discharge stream to be added to said product water stream.